Radiation Effect Studies on ALPIDE at 88” Cyclotron

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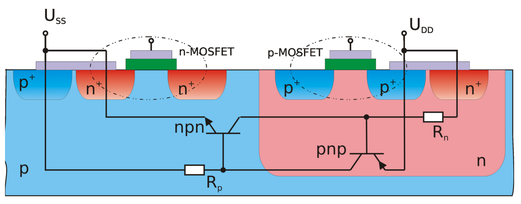
INTRODUCTION

We compared the Single Event Latch-up (SEL) sensitivity of the first and latest prototypes of ALPIDE (ALICE PIxel DEtector), a CMOS pixel sensor designed for use in the new ALICE Inner Tracking System.

SELs are a common problem with CMOS technology. They originate due to the presence of parasitic structures in the sensor substrate (paired PNP and NPN transistors). When a heavy ion hits the sensor, one of these transistors may be forced into conduction. This pulls the gate of the second transistor to a voltage that brings it into conduction. At this point each transistor keeps the other in conduction which causes the flow of a high current through the parasitic structure. Such currents, if held for a long time, can permanently damage the sensor.

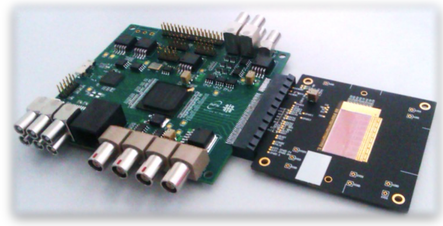


Measuring the SEL sensitivity helps understand if there are regions of the sensor particularly susceptible to latch-up and if other design approaches in these regions may be preferable.

ALPIDE

The ALPIDE sensors are MAPS (Monolithic Active Pixel Sensors), that integrate both the sensitive volume and the front end electronics in the same silicon wafer. Each pixel contains an analog and a digital section. The sensor features[1]:

- **In-pixel discriminators and digital memory** where hit information is saved and stored digitally until read-out.
- **In-matrix address encoders** that encode the addresses of hit pixels which are then read out. Reading only hit pixels reduces read-out time and preserves full hit information.
- **An end–of-column read-out circuit** where data is compressed and buffered before being transmitted to off detector electronics.



EXPERIMENT AND RESULTS

Latch-up cross section, an average value used to indicate latch-up susceptibility in a CMOS chip, is defined as

$$\sigma = {}^{N}/_{F}$$

where F is ion fluence and N is the number of latch-ups corrected for dead time using

$$N = \frac{N_0}{1 - N_0 \frac{\tau}{t}}$$

where N_0 is the number of latch-ups observed in a test, t is the duration of the test and τ is the measured dead time.[3]

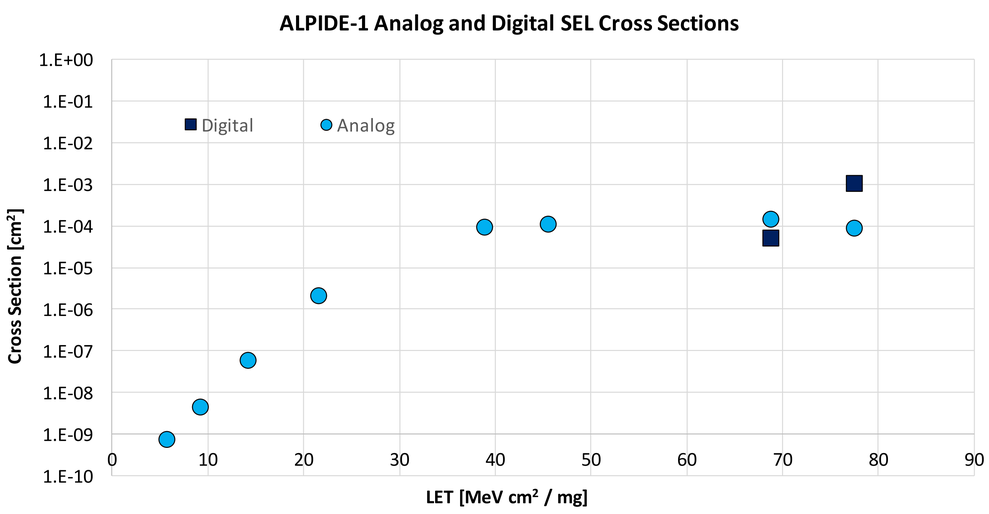
We measured the cross section for latch-up by using a cocktail beam from the LBNL 88-inch cyclotron to deposit energy in the sensor. These measurements are complemented by a set of other measurements carried out at HIF (Louvain-la-Neuve).

The measurements were carried out with ion cocktails at different energies for ALPIDE-1 and ALPIDE-4. The Linear Energy Transfer (LET) values used are listed in the table below.[2,5]

ALPIDE-1		ALPIDE-4	
Ion	LET (MeV cm²/mg)	Ion	LET (MeV cm²/mg)
Ne	5.77	Ne	2.39
Si	9.28	Ar	7.27
Ar	14.32	V	10.9
V	21.68	Cu	16.53
Kr	39.25	Kr	32.5
Y	45.58	Xe	62.5
Xe	68.84		
Tb	77.52		

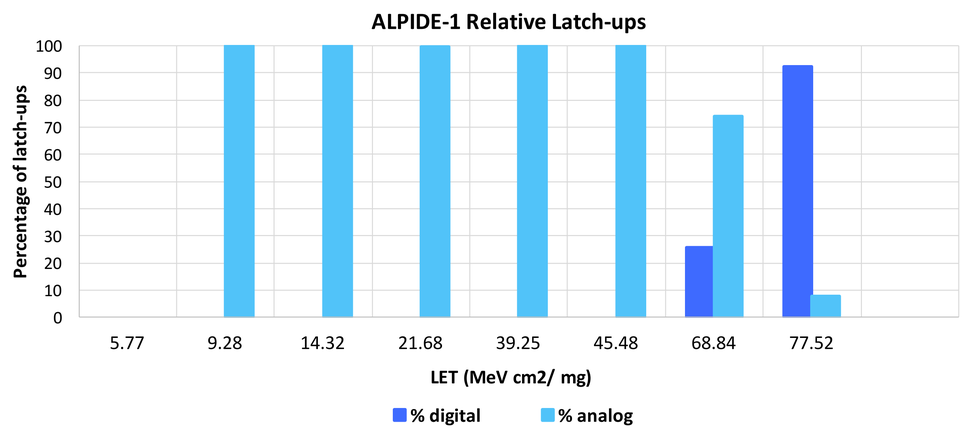
The digital and analog currents of the sensor are monitored continuously. Thresholds for both currents are set before each run. One millisecond after an over-current event, the sensor power-cycles automatically.

ALPIDE-1 MEASUREMENTS



The above plot shows the SEL cross sections for both the analog and digital sections of ALPIDE-1. Digital cross sections are shown with dark blue squares. Analog latch-up cross sections are shown with light blue circles. The point at LET = 5.77 is an upper limit; no events were observed.

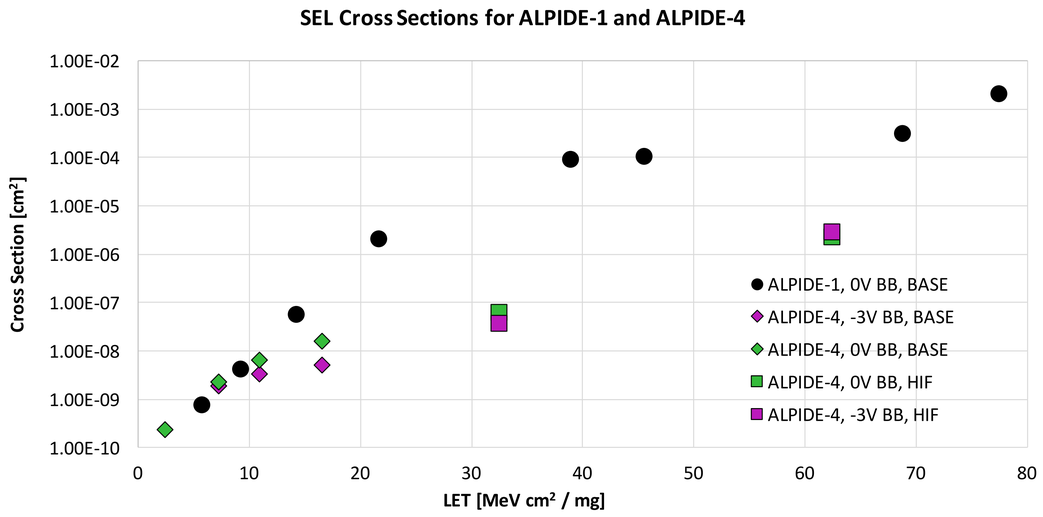
At high LETs ($\gtrsim$ 70 MeV cm²/mg) the digital latch-up cross section becomes comparable, and even greater, than the analog. This is shown in the plot below, which depicts the relative percentages of digital and analog events.



COMPARISON WITH ALPIDE-4

Based on these measurements of ALPIDE-1, changes were made to succeeding prototypes of the sensor. Specifically, the contact area of the p^+ wells inside the matrix was increased to reduce the resistance to the substrate, which reduces the gain of the parasitic circuit which initiates a latch-up.

The plot below shows the comparison between the cross sections of the two sensors. Results for ALPIDE-1, at 0V bias voltage, are shown in black. The rest of the points are for the ALPIDE-4 sensor. In this case, both 0V and -3V bias voltages were used. The diamonds represent ALPIDE-4 measurements done at the BASE facility (88” cyclotron). The squares are complimentary measurements done at HIF[5]. It is clear that ALPIDE-4 is less susceptible to latch-ups at higher LETs.



Only digital latch-ups were seen in ALPIDE-4. This shows that the changes made to mitigate analog latch-up sensitivity were effective.

The bias voltage did not have a significant effect on latch-up cross sections.

CONCLUSIONS

- For the LET values foreseen in ALICE after the upgrade (below 14 MeV cm²/mg)[8] the latch-up cross sections are below 10^{-7} cm².
- For ALPIDE-1, mainly analog latch-ups were seen. For ALPIDE-4, only digital latch-ups were seen. The analog cross sections are lower for ALPIDE-4 at all LET values.
- There is a clear improvement in latch-up susceptibility between ALPIDE-1 and ALPIDE-4.
- In these studies we classify any event where a current exceeded a threshold as a latch-up. This includes many events where the high current lasts less than 1 millisecond. The cross section for sustained latch-ups is lower than the values presented here.
- The effect of bias voltage on latch-up cross section seems to be irrelevant.

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